

Static lamination micro-mixer

5 The invention relates to a micro-mixer for mixing, dispersing, emulsifying or suspending at least two fluid phases, it being necessary for this micro-mixer to have at least one slotted plate having slot openings and an aperture plate having aperture slots arranged above the former. The slot openings in the slotted plate(s) and aperture plate(s) are formed as continuous openings. The opening can be shaped as desired; the opening preferably has a simple geometry (for example a hole or rectangular slot).

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Static micro-mixers are key elements in micro-reaction technology. Static micro-mixers use the principle of multi-lamination, in order in this way to achieve rapid mixing of fluid phases by means of diffusion. A geometric configuration of alternately arranged lamellae makes it possible to ensure good mixing in the microscopic range. Multi-lamination mixers made of structured and periodically stacked thin plates are already extensively described in the literature; examples of this will be found in German patents DE 44 16 343, DE 195 40 292 and the German patent application DE 199 28 123. In addition, as opposed to the multi-lamination mixers, which comprise structured and periodically stacked thin plates, the German patent application DE 199 27 554 describes a micro-mixer for mixing two or more educts, the micro-mixer having mixing cells. Each of these mixing cells has a feed chamber which is adjoined by at least two groups of channel fingers which engage in the manner of a comb between the channel fingers in order to form mixing regions. Above the mixing region there are outlet slots, which extend at right angles to the channel fingers and through which the product emerges. As a result of the parallel connection in two spatial directions, a considerably higher throughput is possible.

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The invention specified in Patent Claim 1 is based on the problem that micro-mixers can clog up with contaminating particles and therefore tend to block; as a result of the inadequate cleaning possibilities, there is a considerable restriction of the possible uses of micro-mixers. In the case of the micro-mixers constructed from plates, the plates are preferably permanently connected to one another and, as a result, the micro-structures are no longer freely accessible; cleaning of the micro-

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mixers described is therefore not possible in a straightforward manner. In order to clean a corresponding micro-mixer, the plate stack has to be dismantled, which generally proves to be very complicated.

- 5 These problems are solved by the static lamination micro-mixer described in Patent Claim 1 which, in order to mix at least two fluid phases, contains at least one slotted plate having slot openings and an aperture plate having aperture slots arranged above the former. The slot openings are generally formed as continuous openings.
- 10 The advantages achieved by the invention consist in the fact that the static lamination micro-mixer can be produced economically, is easy to clean and the fluids to be mixed are mixed rapidly and effectively with one another. In addition, the pressure loss is so low that it can even be used for large throughputs.
- 15 Advantageous refinements of the invention are specified in Claim 2 and those following. According to Claim 2, the number of aperture slots in the aperture plate and/or the number of slot openings in the slotted plate can be greater than 1. In the slot openings of the slotted plate, according to Claim 3, the fluid flows led out of various regions of the fluid distribution are led in such a way that they enter the slot
- 20 opening of a slotted or aperture plate located above. According to Claim 5, the fluid phases come together in the slot openings of the aperture plate. The slot openings in the slotted plate can in this case be offset parallel to one another and/or arranged in a periodic pattern in relation to one another. By means of a suitable geometric form and alignment, slot openings according to Claim 6 in the slotted plate can promote
- 25 the production of secondary effects. These effects can be produced, for example, by separations of vortices behind the plates or by transverse components from the feed lines. The mixing at the molecular level as a result of diffusion is consequently overlaid by secondary flows, which lead to a shortening of the diffusion paths and therefore the mixing times. According to Claim 7, the slot openings can be arranged
- 30 obliquely in relation to one another. A further refinement permits the slot openings to be configured in the manner of funnels or lobes. This refinement of the forms can be expedient in order to achieve a uniform pressure distribution in the feed channels. This is a precondition in order to arrive at a uniform mixing quality in the entire

component. Furthermore, it is possible for a plurality of slotted plates and/or aperture plates to be arranged offset from one another directly above one another. Deflection of the flow can be achieved according to Claim 9 if slotted plates and/or aperture plates located directly above one another or arranged offset from one another are used. The deflection action can be used, according to Claim 11, to lead the one or more fluid flows specifically to the metering point of one or more fluid flows.

The mixing chamber can be fitted above the aperture plate, according to Claim 12. According to Claim 13, it is also possible for the aperture slots in the aperture plate to be offset parallel to one another and/or arranged in a periodic pattern in relation to one another. A further advantageous refinement of the invention permits the slot openings in the slotted plate and the aperture slots in the aperture plate to be arranged rotated at any desired angle, preferably 90°, in relation to one another. According to Claim 15, it is additionally possible for the slot openings in the slotted plate and the aperture slots in the aperture plate to have a width of less than 500 µm. In order to improve the result when mixing liquids, emulsifying or suspending, slot openings with widths smaller than 100 µm have in particular proven to be worthwhile. The width of the slot openings in the slotted plate is the same for all fluid phases in the basic type of the mixer. However, it has been shown that, in the case of combining fluids which differ in terms of their viscosity and/or in which the volume flows are in a numerical ratio with one another different from 1:1, it may be advantageous if the width and/or shape and cross-section of the slot opening in the slotted plate differ for the various fluids. A further advantageous refinement permits the slotted and aperture plates to consist, partly or completely, of metal, glass, ceramic and plastic or else of a combination of these materials. According to Claim 17, the slotted and aperture plates can be produced by punching, embossing, milling, erosion, etching, plasma etching, laser cutting, laser ablation or by the LIGA technique but preferably by laser cutting or the LIGA technique. A further advantageous refinement permits the slotted and aperture plates to comprise a stack of micro-structured thin plates; these thin micro-structured plates can be connected materially to one another by means of soldering, welding, diffusion welding or adhesive bonding or with a force fit by means of screwing, pressing (for example in a housing) or riveting. An

advantageous refinement according to Claim 20 permits the aperture slots in the aperture plate and the slot openings in the slotted plate to be of branched configuration. The static micro-mixer obtained in this way can, according to Claim 21, be accommodated in a housing provided for the purpose. According to Claim 22, the housing can contain channels and in this way permits spatial distribution of the fluids. According to Claim 23, these channels can be arranged parallel to one another, radially, concentrically or behind one another. In order to achieve a suitable distribution of the speeds along the channels, it may be advantageous to maintain or to vary the cross sections over their length, according to Claim 24.

According to Claim 25, the micro-mixer can be used individually or as a constituent part of a modularly constructed arrangement for carrying out physical or chemical conversions or, according to Claim 26, together with other functional modules, integrated into one component.

Exemplary embodiments of the inventions are illustrated in the drawings and will be described in more detail below.

In the drawings:

Fig. 1 shows a schematic illustration of the static micro-mixer comprising a slotted plate and an aperture plate;

Fig. 2a shows an exploded illustration of a static lamination micro-mixer comprising lower housing part (10), feed channels (11), slotted plate (20) and aperture plate (30);

Fig. 2b shows an illustration of a static lamination micro-mixer comprising lower housing part (10), feed channels (11), slotted plate (20) and aperture plate (30);

Fig. 3a shows a plan view of the feed channels (11), slot openings (22a, 22b) and aperture slots (31) of a static lamination micro-mixer;

- Fig. 3b shows a plan view of the slot openings of different geometry and orientation (22) in a slotted plate (20) of a static lamination micro-mixer;
- 5 Fig. 3c shows a plan view of the slot openings of different geometry and orientation (22) in a slotted plate (20) of a static lamination micro-mixer;
- Fig. 3d shows a plan view of the slot openings of different geometry and orientation (22) in a slotted plate (20), the slot openings for both fluids overlapping in
10 the plane of the slotted plate;
- Fig. 3e shows a plan view of the slot openings of different geometry and orientation (22) in a slotted plate (20), the slot openings having different widths and forms;
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- Fig. 3f shows a plan view of the slot openings of different geometry and orientation (22) in a slotted plate (20), the slot openings, the aperture slots (31) and/or the feed channels (11) having different and variable widths and forms;
- 20 Fig. 4a shows a plan view of a static lamination micro-mixer comprising lower housing part (10), slotted plate (20) and aperture plate (30);
- Fig. 4b shows a plan view of a static lamination micro-mixer;
- 25 Fig. 5 shows an exploded illustration of a static micro-mixer;
- Fig. 6 shows an exploded illustration of a static micro-mixer with the viewing angle from below;
- 30 Fig. 7a shows a schematic illustration of the lower housing part (10);
- Fig. 7b shows a cross section through lower housing part (10) along the plane B-B;

Fig. 7c shows a cross section through lower housing part (10) along the plane C-C;

Fig. 8a shows a schematic illustration of a static micro-mixer having two different slotted plates and slot openings (22, 23) arranged offset in relation to one another;

Fig. 8b shows a schematic illustration of an assembled static lamination micro-mixer having two different slotted plates;

Fig. 9a shows exploded illustrations of lamination micro-mixers with a parallel offset arrangement of the channels in order to divide the fluids in the housing;

Fig. 9b shows exploded illustrations of lamination micro-mixers having a radially concentric arrangement of the channels in order to divide the fluids in the housing;

Fig. 10 shows a lamination micro-mixer (60) (cf. Fig. 9a) as a constituent part of an integrated process arrangement together with a heat exchange unit (70).

Fig. 1 shows a schematic illustration of a static lamination micro-mixer comprising lower part 10, a slotted plate 20 and an aperture plate 30. The lower part 10 contains the feed channel 11a for the fluid A and the feed channel 11b for the fluid B. The slotted plate 20 has slot openings 22a and 22b for the fluids A and B, which are fed from the feed channel 11a and 11b. Above the slotted plate 30 there is the aperture plate 30 having an aperture slot 31. In this case, the aperture plate 30 covers the outer region of the slot openings 22a and 22b, the central region of the slot openings 22a and 22b overlapping the aperture slot 31 and remaining free as a result.

Fig. 2a shows the exploded illustration of a static micro-mixer comprising lower part 10, feed channels 11a and 11b, slotted plate 20 and aperture plate 30. The feed channels 11a and 11b in each case contain the fluids A and B; above these feed channels there is the slotted plate 20 having the slot openings 22a and 22b. Located

above the latter is the aperture plate 30, whose aperture slots are arranged at an angle of 90° in relation to the slot openings 22a and 22b.

Fig. 2b shows a schematic illustration of a static micro-mixer, as illustrated in Fig. 2a, comprising lower part 10, slotted plate 20 and aperture plate 30.

Fig. 3a shows slot openings 22a and 22b arranged as double rows in the form of slotted regions 21. These slotted regions 21 are fed with fluids through the feed channels 11a and 11b. One half of the slot openings 22a overlaps the feed channels 11a, the other overlaps the feed channels 11b. In the central region of the double rows, the slot openings 22 overlap the aperture slot 31 fitted above. The slot openings 22 can also be arranged obliquely, as illustrated here.

Fig. 3b, Fig. 3c, Fig. 3d, Fig. 3e and Fig. 3f show slot openings 22 with different geometric configuration and orientation. Underneath the slot openings there are the feed channels 11. Above the slot openings there are the aperture slots 31. The cross sections of the feed channels 11 and of the aperture slots 31 can vary along the course (Fig. 3f). The slot openings 22 can be widened in the shape of a funnel. The width and form of the slot openings 22 can vary between the fluids (Fig. 3e) and within the fluids (Fig. 3f).

Fig. 4a shows the plan view of a lower housing part 10. The lower housing part 10 is provided with numerous slot-like feed channels 11a and 11b, which are illustrated as displaced alternately to the right or left. In the slotted plate 20 arranged above it there is the slotted region 21 illustrated as black bars; here, the slotted region 21 is in each case positioned between two feed channels 11a and 11b, so that it is overlapped by two feed channels. The aperture slots 31 of the aperture plate 30 located above are found centrally above the slotted regions 21 of the slotted plate 20.

Fig. 4b shows a schematic arrangement of feed channels 11a and 11b, slotted regions 21 and aperture slots 31.

Fig. 5 shows the exploded view of a static lamination micro-mixer; the micro-mixer

comprises lower housing part 10 and upper housing part 40. Located between the lower housing part 10 and upper housing part 40 are the slotted plate 20 and the aperture plate 30. In the lower housing part 10 there is a groove 13, into which a sealing ring 50 can be inserted in order in this way to seal off the micro-mixer with respect to the surroundings. The lower housing part 10 and the upper housing part 40 are each provided with openings for fixing elements 44, by means of which the two can be fixed to each other. The lower housing part 10 contains on the outer surface two fluid inlet channels 12a and 12b for the fluids A and B to be mixed. Machined on the upper side of the lower housing part 10 are numerous slot-like feed channels 11a and 11b, which are configured to be lengthened alternately to one or the other side and can thus be fed with fluid A or fluid B. The slotted plate 20 contains numerous slotted regions 21; above the slotted plate 20 there is fitted the aperture plate 30, which has a large number of aperture slots 31. The upper housing part 40 contains a fluid outlet 42 for the discharge of the mixture obtained.

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Fig. 6 shows, in analogy with Fig. 5, an exploded illustration of a static lamination micro-mixer with a viewing angle from the underside. The upper housing part 40 contains a large mixing chamber 45, into which all the aperture slots 31 of the aperture plate 30 open. In order to support the aperture plate 30, a plurality of supporting structures 41 are fitted in the upper housing part 40.

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Fig. 7a shows the schematic illustration of the lower housing part 10. The lower housing part 10 is provided with feed channels 11a and 11b for the fluids A and B to be mixed. There are fluid inlets 12a and 12b on the outer sides of the lower housing part. The cutouts 44 in the four corners of the lower housing part 10 permit it to be fixed.

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Fig. 7b shows the cross section through the lower housing part 10 along the line B-B in Fig. 7a. The fluid inlet 12a continues into the fluid inlet channel 14 for the fluid A. On the upper side of the fluid inlet channel 14 there are the feed channels 11a for the fluid. On the upper side of the lower housing part 10 there is a groove 13 for the insertion of a sealing ring.

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Fig. 7c shows the cross section through the lower housing part 10 along the line C-C in Fig. 7a. The feed channels 11a for the fluid A and 11b for the fluid B run alternately parallel without there being any cross connection between these two feed channels. On the upper side of the lower housing part 10 there is again a groove 13
5 for the insertion of a sealing ring.

Fig. 8a shows the schematic illustration of a static lamination micro-mixer having the two different slot openings 22a/22b and 23a/23b. The slot openings 22a and 22b of the first slotted plate form the feed channels for the second slotted plate having small
10 slot openings 23a and 23b. The slot openings 22a/22b and 23a/23b are in each case rotated through 90° in relation to one another.

Fig. 8b shows the plan view of such a static micro-mixer according to Fig. 8a comprising two different slotted plates, whose slot openings are rotated through 90°
15 in relation to one another.

Fig. 9a and Fig. 9b show two exemplary embodiments of lamination micro-mixers in an exploded illustration. According to these, the slot openings in the slotted plate, the slot openings in the aperture plate and also the channels for distributing the fluids
20 can be arranged to be offset circularly or in parallel.

Fig. 10 shows an exemplary embodiment relating to the use of a lamination micro-mixer as a constituent part of an integrated arrangement for carrying out physical-chemical conversions. In the case presented, lamination micro-mixer (60) and
25 bundled-tube heat exchanger (17) are integrated into one component.

List of reference symbols

| | |
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| 10, 10a | Lower housing part |
| 11a | Feed channel for fluid A |
| 11b | Feed channel for fluid B |
| 12a | Fluid inlet for fluid A |
| 12b | Fluid inlet for fluid B |
| 13 | Groove for sealing ring |
| 14 | Fluid inlet channel |
| 20 | Slotted plate |
| 21 | Slotted region |
| 22a | Slot opening for fluid A |
| 22b | Slot opening for fluid B |
| 23a | Slot opening for fluid A |
| 23b | Slot opening for Fluid B |
| 30 | Aperture plate |
| 31 | Aperture slot |
| 40, 40a | Upper housing part |
| 41 | Supporting structure |
| 42 | Fluid outlet |
| 44 | Opening for fixing element |
| 45 | Mixing chamber |
| 50 | Sealing ring |
| 60 | Micro-mixer |
| 70 | Bundled-tube heat exchanger |